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To cite this article: K E Bondar *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 022086

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The Change of Operational Properties of Polyvinylchloride Film on Exposure to Microwave Radiation

K E Bondar¹, D F Suleymanov¹, S V Laponov¹

¹Ufa State Petroleum Technological University, Branch in the Sterlitamak, Prospekt Oktyabrya St., 2, 453118, Republic of Bashkortostan, Russia

E-mail: suldf@yandex.ru

Abstract. The article considers the study of polyvinylchloride film properties and their change on exposure to microwave radiation with relatively low doses of energy. The work relevance is caused by wide application of products on PVC basis and their good interaction with electromagnetic radiation. The experiments have shown the improvement of operational properties at energy doses from 10 to 30 kJ / kg. The proposed method is more environmentally friendly, energy efficient compared with traditional methods of improving the polyvinylchloride film properties.

1. Introduction

Improving the physical and mechanical properties of polymer materials is an urgent challenge, and its solution should significantly improve the quality and service life of polymer products. In recent years, a large number of papers have been published showing the results of successful application of ultrahigh-frequency electromagnetic radiation (microwave EMR) to modify the physical and mechanical properties of polymer materials [1-4]. At the same time, the most interesting is the so-called non-thermal modification of polymers, when the amount of microwave energy absorbed by the substance does not lead to a significant change in the temperature of the material, but makes a significant change in the physical and mechanical properties. This paper presents the results of an experimental study of polyvinyl chloride property changes at different doses of absorbed microwave EMR energy. The relevance of such studies is due, on the one hand, to the wide use of this polymer in manufacturing various products, in particular, for large-capacity production of insulating coating of pipeline systems [5], and on the other hand, a relatively high (compared with other polymers) microwave radiation absorption. So, for example, as follows from the experimental data given in [6], the characteristic penetration depth of microwave EMR into the polymer substance, in which the electric field intensity vector decreases by e times ($e \approx 2.7$ - base of the natural logarithm) at emission frequency of 2.45 GHz, for polyvinyl chloride is about 10 cm, for polyethylene terephthalate – about 28 cm, polypropylene – about 34 cm, polyethylene is about 41 cm.

2. Experimental procedure. Results and discussion

The pilot installation on studying the interaction of polyvinylchloride with microwave EMR consisted of a microwave generator with a changeable power output up to 1 kW with a radiation frequency of 2.45 GHz, an emitting system, a working chamber, adjusting the loads and equipment for measuring



the power and temperature of the sample. By changing the mass of the sample, the exposure time and emission power it was possible to change the specific (J/kg) dose of the absorbed radiation [7].

Figure 1 shows the observed dependence of tensile strength change of polyvinylchloride film and electrical resistance depending on the specific absorbed energy of microwave EMR. Measurement of mechanical properties, in particular, the actual breaking stress was carried out according to GOST 25945 and GOST 2678. The absolute actual breaking stress of non-radiated PVC film was ~38 MPa.

Determining the electrical resistivity of the polyvinylchloride film was being carried out by times of charge leakage at a constant humidity.

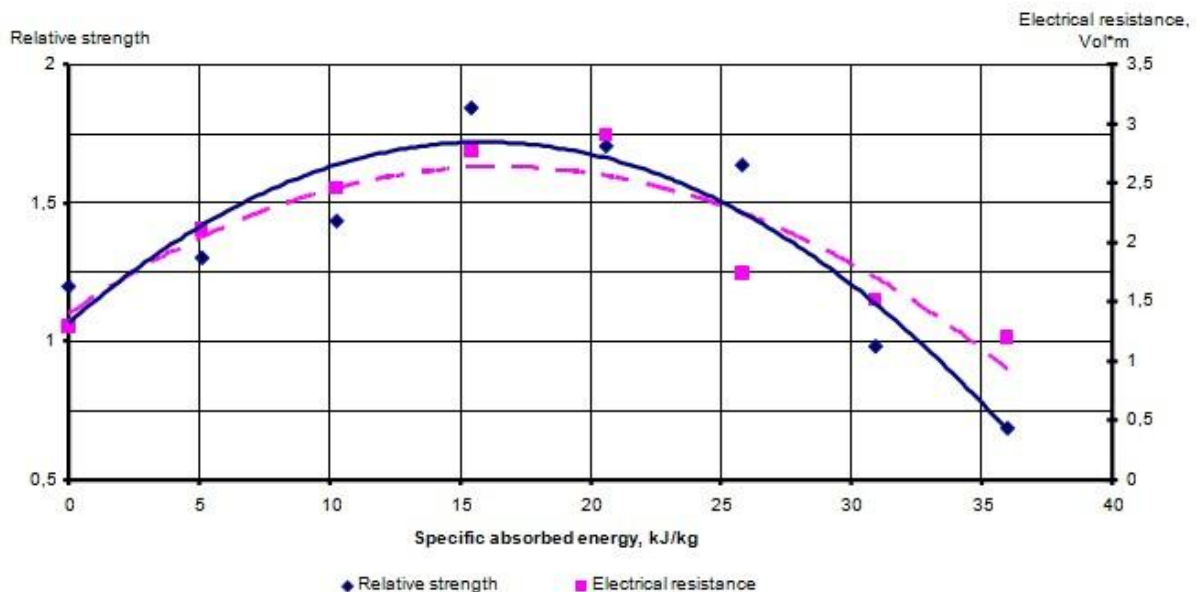


Figure 1. Dependence of tensile strength on specific absorbed energy.

As it follows from the above dependences that there is a slight increase of strength properties with a specific absorbed energy being less than 10 kJ/kg, and at a dose of more than 30 kJ/kg, there is a decrease compared with an unmodified sample. In the energy range from 15 to 20 kJ/kg there is an increase in the actual breaking stress for more than 1.5 times. The same graph shows that with the specified range of the radiation dose of microwave EMR the volumetric electric resistivity, determined by the presence of free charges in the polymer and their mobility, shows the maximum value. Thus, it can be assumed that with an increase in the specific electrical resistance, there is a decrease in free charges, due to the formation of additional bonds and conformational changes of macromolecules, which leads to an increase in tensile strength [8-10].

Moisture regain in polymer films used for insulating coatings is to be one of the defining parameters along with mechanical strength and adhesion.

Figure 2 shows the dependence of moisture regain in polyvinylchloride film modified in microwave electromagnetic field as for the exposure time. As well as in the previous case, in the range of 10-20 kJ/kg doses there is a halve reduction of moisture regain. The decrease in values can be explained by the increase of spatial grid density of polymer macromolecules due to the formation of cross bonds. At the same time, the swelling rate decreases, indicating the creation of more rigid structure of the modified polymer.

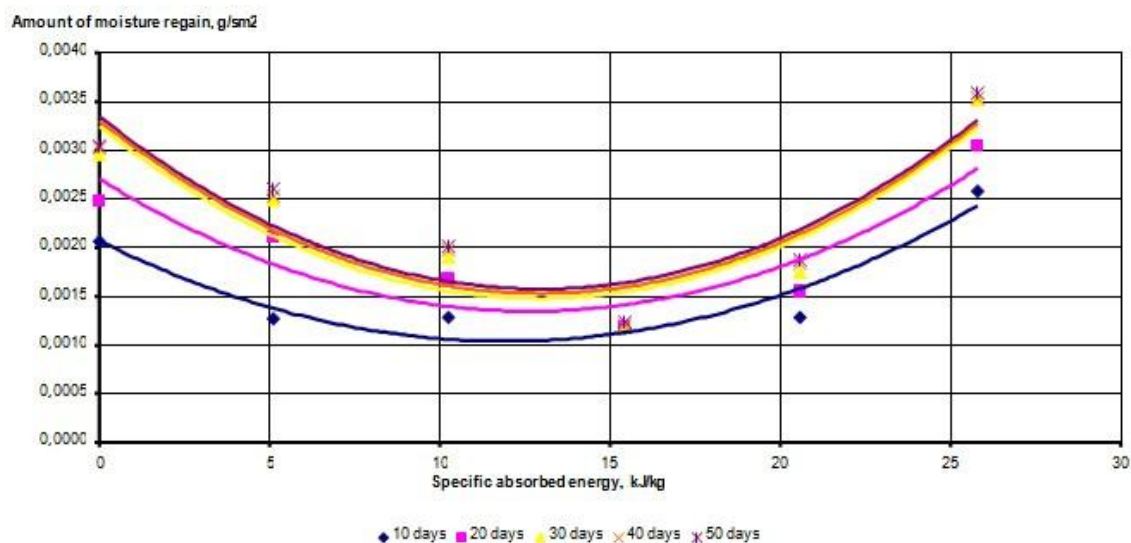


Figure 2. Dependence of moisture regain on specific absorbed energy.

To identify the mechanism of microwave EMR influence on polyvinylchloride structure, the differential-scanning calorimeter studies were carried out to determine the glass transition temperature, the temperature and starting time of hydrogen chloride release and the polymer heat capacity. Experimental studies were carried out using the DSC Q200 device with a step heating mode at a speed of 10 °C/min. The results of the experiments are shown in Figure 3.

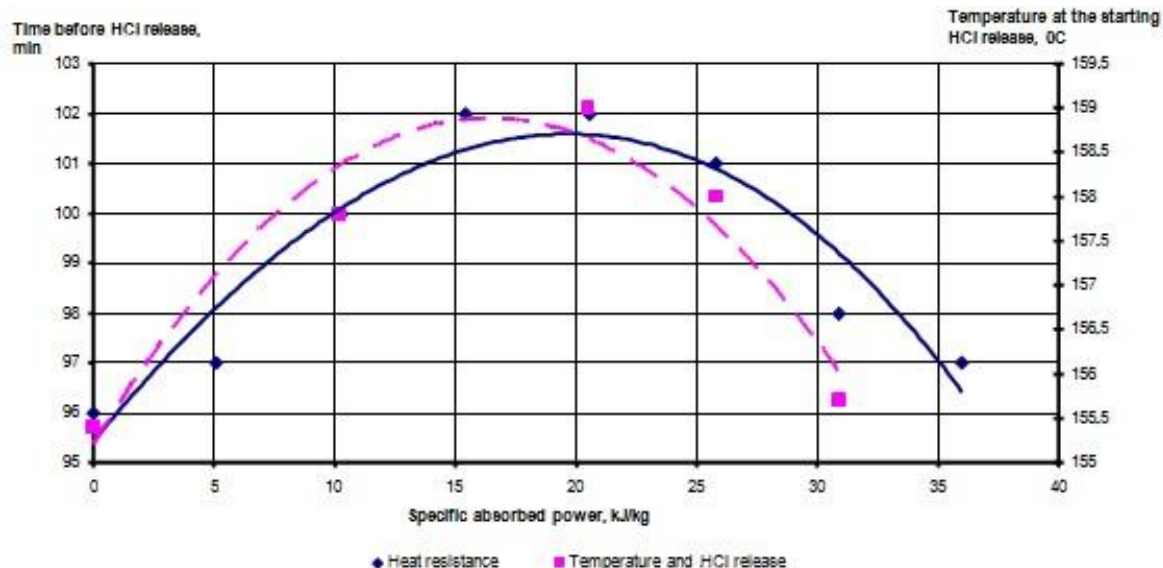


Figure 3. Dependence of time and temperature of starting HCl release on specific absorbed power.

As we can see from the above graphs there is an increase in the time and temperature of the starting HCl release in the range of doses from 12 to 23 kJ/kg. Increasing time of dehydrochlorination of PVC film allows us to conclude that the increase in mechanical strength in this range of microwave doses is not due to hydrogen chloride release, but the mechanisms associated with the formation of additional intermolecular bonds under the influence of an electromagnetic field.

The results of the experiments on the interaction of polyvinylchloride with electromagnetic radiation of the ultrahigh frequency range shows that there is an irradiation dose interval of 10-20 J/kg, which makes a

creation of additional relationship between the polymer macromolecules and their conformational changes leading to an increase in mechanical strength, electrical resistance and a decrease in moisture regain.

To confirm this approval there was a study of polymer insulating materials by the images of their structure (Figure 4) obtained with the use of scanning probe microscope with high resolution type NT-MDT Integra Prima in atomic force mode, using a probe type NSG11.

The PVC film not-treated by microwave radiation has an amorphous structure (Figure 4A). Under the influence of microwave radiation the orientation of the lateral branches of PVC macromolecules changes, which contributes to the growth of a number of crystallization centers, ordering the structure and the reduction of free volume areas in it [11].

As a result, the total volume of amorphous regions of the structure decreases due to the resulting crystalline phase (Figure 4B), which is accompanied by an increase in the degree of ordering in the arrangement of polymer macromolecules. PVC molecules are rebuilt in parallel lines, which represent a sign of the growth of its crystallinity, which improves the physical and mechanical properties of PVC film [12].

The results of this experiment has shown that being exposed of PVC to UHF EMR there are "new" supramolecular formations, providing the improved physical and mechanical properties of the polymer material, the main reason for their creation is the movement of polymer chains inside the crystalline formations initiated by electromagnetic effects.

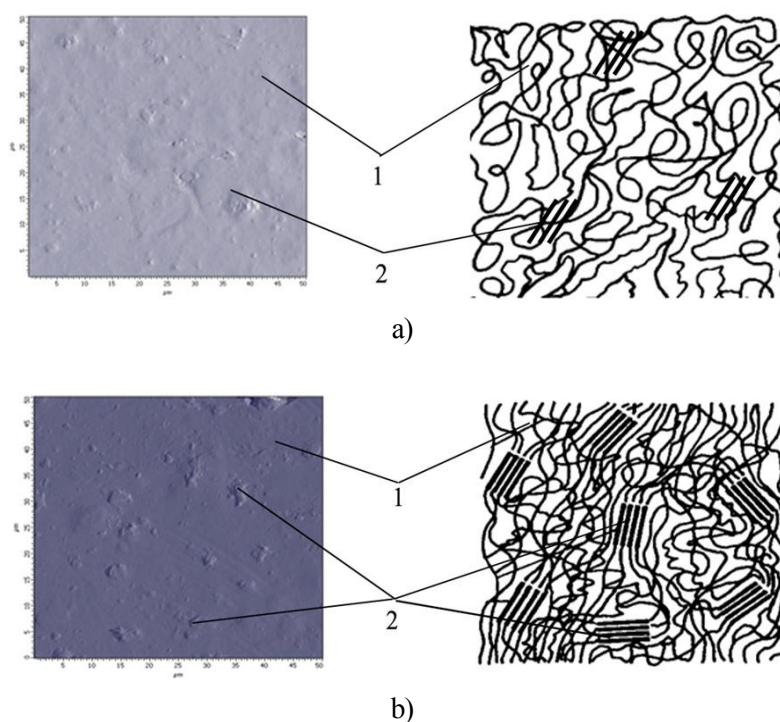


Figure 4. Structure of PVC film. 1 – non-crystalline; 2 – crystalline; a – without MW treatment; b – after MW treatment (15 kJ/kg).

3. Conclusion

The principal possibility of using microwave radiation for carrying out purposeful reconstruction of polar polymer structure providing the improvement of physical and mechanical properties has been experimentally proved. In addition, the investigated method of improving the operational characteristics has less energy consumption and more environmentally friendly than the traditional method [13, 14] of hardening, wherein the energy costs are about 40-80 kJ/kg. This makes it possible to develop an effective technology [15] and apparatus [16] by the use of electromagnetic radiation to improve the performance of polyvinylchloride products.

4. References

- [1] Kalganova S G 2009 *Thesis for the degree of doctor of technical Sciences: 05.09.10*
- [2] Hosur M V, Menon A, John M K, Rangari V K, Jeelani S 2005 *International SAMPE symposium and exhibition* **50** 1659-1669
- [3] Das S, Mukhopadhyay A K, Datta S, Basu D 2008 *Indian Academy of Sciences* **31(7)** 943-956
- [4] Dariusz Bogdal, Aleksander Prociak 2007 *Chemistry Today* **25(3)** 30-33
- [5] Basiev K D, Bigaliev A A, Kozaev M Y 2005 *Bulletin of the Vladikavkaz scientific center* **5(1)** 47-53
- [6] Abakaev E M, Suleymanov D F, Shulaev N S 2011 *Butlerov messages* **24(1)** 95-98
- [7] Rabek J 1983 *Experimental methods in polymer chemistry* 480
- [8] Tager A A 1968 *Physical chemistry of polymers* 536
- [9] Tugov I I, Kostyukina G I 1989 *Chemistry and physics of polymers* 432
- [10] Brown V 1961 *The dielectrics* 326
- [11] Kryzhanovskii V K 2003 *The technical properties of polymeric materials* 240
- [12] Bartenev G M, Zelenev Yu V 1976 *Course of polymer physics* 288
- [13] Vorobev V A, Andrianov R A 1985 *Technology of polymers* 303
- [14] Kargin V A *Encyclopedia of polymers* **1** 1224
- [15] Suleymanov D F, Shulayev N S, Bondar K E, Usinger A A 2017 *Sciences of Europe* **13(2)** 94-98
- [16] Suleimanov D F, Shulayev N S, Bondar K E, Laponov S V, Uzinger A A 2017 *IOP Conference Series: Earth and Environmental Science. "Innovations and Prospects of Development of Mining Machinery and Electrical Engineering - Transportation of Mineral Resources"* 062013